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A SYSTEMS VIEW OF FISHERY MANAGEMENT WITH SOME NOTES ON THE TUNA FISHERIES

by

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ROME, 1971

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PREPARATION OF THIS PAPER

This paper was originally presented at the 14th Session of the Indo-Pacific Fisheries Council, at Bangkok, Thailand, in November 1970. A shortened version is continued in the IPFC Proceedings. The full version is being issued by the Fishery Economics and Institutions Division of the Department of Fisheries of FAO, in the belief that it will be of general value at a time when the systems approach to fisheries problems is attracting considerable interest.

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1 INTRODUCTION

Contemporaneous technological development is at high level and continues to accelerate and yet, unfortunately, at the same time, many of the serious problems of the world have not been ameliorated by this development - indeed, in some instances the problems have become more severe. It is a seeming paradox, that we have, in fact, in principle, the technological capability of solving many of these problems and yet in many instances solutions have not been forthcoming (cf. Churchman, 1968). The reasons for this paradox lie in the fact that our problems are no longer as simple as they once were and techniques carried over from more halcyon days when problems could be solved on a piecemeal basis, in a more or less leisurely fashion, are no longer adequate for reaching efficient solutions to our present day problems, which have reached such complexity that we might call them superproblems. Fortunately, however, techniques have been developed and are being developed to handle these superproblems. These techniques are oriented toward asking the "right questions" and are collectively called systems analysis.

Fisheries management, just as the other problems to which we have alluded, has also increased in complexity from the days when students considered the resources of the sea to be inexhaustible; when fishery management essentially involved examining the dynamics of relatively few species in vacuo; when interesting biological questions took precedence over questions of the dynamics of the stocks; or when the limited mobility and moderate fishing power of fishing vessels virtually obviated the need for considering international aspects of fishery management. By contrast, we have today a situation in fisheries where individual fishing operations can exert tremendous intensities of fishing effort and deplete a stock in a matter of weeks or months; where the number of overexploited stocks continues to grow; where some stocks continue to become virtually extinct; and where the community of individuals who harvest and process the stocks are, in many instances, neither held accountable nor do they demonstrate a responsibility to conserve the stocks by not overfishing, by not insisting on and supporting research of relevance to fishery problems; and by not contributing needed management data or contributing data that either contain an inordinate amount of errors or are not timely. These complexities require that the contemporaneous manager face the above questions and answer even more complex questions concerning how resources should be allocated in the time stream, how resources should be allocated among the states, and how criteria should be established to evaluate the resources so that appropriate allocations can be accomplished.

These complexities afforded by fisheries have been recognized, in varying degrees, over the last two decades. For example, Chapman (1966), reflected upon the involvement of fisheries with institutional problems and Holt (1969) observed, perhaps wistfully, that

> "... Many of us were optimistic when 20 years ago we began proposing quite reasonable net-mesh regulations to conserve the young of certain fish stocks. Then we saw these simple - I suppose oversimple - ideas bog down in consideration of precisely how to measure a particular kind of twine, and how to take account of the innumerable special situations that countries pleaded for, so that fishery research seemed to be becoming perverted from its earlier clarity and broad perspective." 1/

Even though there has been growing recognition that fisheries management is a complex of many problems, it appears that we have not adequately recognized the need to develop techniques to handle these problems.

The traditional pursuit of problem-solving in fisheries generally involved attempts to satisfy the scientific curiosity of a small subset of the very broad community of individuals associated with resource problems. The questions that were asked and the problems that were chosen for solution were philosophically oriented toward the scientific approach. Thus, the view of a problem was borne forth on a spark of intuition; hypotheses were formulated and tested, and the hypothesis which was better than the alternatives was submitted to the scientific community, to await inevitable successor hypotheses. The modus operandi in the scientific approach is to search for knowledge and the solution of problems or the generation of advice was not a primary output of the investigation and furthermore inquiries into the interfacial areas between natural phenomena and the more mundane circumstances of everyday human affairs tended to be discouraged. It is, of course, not our purpose to cast what certainly must be petty aspersions on the scientific method, but rather to point out that adherence to the scientific method may have led to asking the wrong questions about the real-world problems of resource management.

1/ This quotation is of interest from two points of view. First, it described the complexities. Second, it reflects a view which might be antithetical to the systems approach because it reflects a concentration upon the mesh problem itself - a problem which could not be solved without taking a broader, perhaps a systems, view of the special cases of the countries involved.

An important alternative to the scientific method is systems analysis, which I believe contains the scientific method as a subset. In this context systems analysis becomes a mechanism which guides which "science" should be attacked by the scientific method. The distinction between the scientific method and systems analysis has been of fundamental importance to the development of systems analysis. Table 1 follows Quade (1964) in contrasting systems analysis and the scientific method. It is of interest that Gulland (in press) recently drew attention to the scientific method approach in fisheries.

Since systems analysis is a technique for investigating complex problems, and we acknowledge the complexity of the fishery management problem, it seems quite appropriate to apply this sort of analysis to fishery management. It is most difficult in a paper as short as this to detail a systems analysis of fisheries in general, or even to detail an analysis for a group of fisheries such as the tuna fisheries. Instead of detailing an analysis, we will try and provide an exposition on the approach to such an analysis, and in so doing, we will be primarily concerned with some necessary prolegomena and an elucidation of some of the structures and techniques that might be involved in an analysis. Our general theme will be that we are taking too narrow a view of fishery management.

TABLE 1

Contrast Between Orientation of Systems Analysis and the Scientific Method

Systems Analysis	Scientific Method
• Suggests policies	• Seeks contribution to knowledge
• Offers advice	• Seeks understanding
• Philosophy in action	• Seeks predictive ability
• Considers immediate, diverse, and complex questions of practical value	

2 SYSTEMS ANALYSIS

To begin I should like to describe some of the rudiments of the systems approach and then use these rudiments to gain a systems view of fishery management.

The systems approach arose as an outgrowth of the "operational analysis" that was so useful in solving operational problems during the second world war. The central theme in systems analysis involves using the analysis to ask the right question by cycling iteratively through (1) defining objectives, (2) designing alternative systems to achieve these objectives, (3) evaluating the alternatives in terms of costs and effectiveness, (4) questioning the objectives and other assumptions underlying the analysis, (5) using this examination to open new alternatives, and (6) establishing new objectives. Once the new objectives are established, the cycle is re-entered at step (1) and continued until a satisfactory interpretation of the problem solution is needed.

If we were to pursue the first task, the problem of defining objectives, in more detail, we should see that this would involve examining in some detail the formulation of the problem in terms of its context, the assumptions involved, and the criteria that would be used to judge various alternatives. Thus we can see that there is a heavy emphasis on the fomulation and definition of the problem - then, through successive iterations, the problem objectives and definition are continually evaluated and appraised and, perhaps, even reformulated. As the problem is manipulated, various alternative solutions are generated and the worth of any of these is adjudged by the analyst in terms of systems criteria and goals established in the formulation of the problem.

The generation of systems criteria and goals are fundamental to the prosecution of systems analysis and the concepts of suboptimization and proximal criteria are in turn fundamental to establishing the goals and criteria.

The concept of suboptimization reflects from the fact that systems problems are a plexus of sub-problems. Because of this it is not possible to easily grasp and optimize the big or superproblem. Rather, it is necessary to break the big problem into subproblems, each of which we can define

precisely and adequately conceptualize. The danger in this is that optimality in the subproblems may not be consonant with optimality of the entire system and this is the danger of suboptimization. Thus the analyst must suboptimize to grasp a problem, but the suboptimization should be consonant with the goals of the entire system; if it is not, then further iteration analysis cycle is required.

The other concept is that of proximate criteria. We frequently state our goals in terms of rather sweeping generalities. We want to optimize the yield of fish. We want maximum sustained yield. We want fishermen to have a "good" living, etc. A little reflection will show that each of these goals can be interpreted in such a variety of ways that their use in guiding the direction of a system is limited. Because of the operational vagueness of "optimizing yield", "maximum sustained yield", and "good living" the systems analysts construct what are called proximal criteria, which, in contrast to the vague terms, can be used to actually adjudge the performance of the system.

Thus systems analysis involves an iterative examination of a problem being careful not to sub-optimize and concentrate upon too narrow segments of the problem using criteria which might not be consonant with higher level goals of the system. A systems view of a problem involves examining a problem in terms of its context, formulation and assumptions preparatory to analysis.

How does our present view of fishery management fit in with a systems view of fishery management? First of all our present view of fishery management tends to be essentially biological. Although there is an increasing awareness of the economical, biological, legal, etc., aspects of the resource problems, 2/ attention still tends to be focused on finding, for example, that level of effort at which catch is maximized or that level of fishing effort and recruitment size which maximizes yield per recruit. Despite lip service paid to the economic aspects of management, economic considerations seem to have had little influence upon the actual management of fisheries and we must of course face up to the possibility that the economic models are not able to cope with the externalities, the common property nature of the resource, and the stock-producer-processor interaction which seems to assure the processor with a steady flow of raw material at the expense of moving from stock to stock, overfishing each stock seriatim, and thus obtaining a much lower yield than would be obtained by proper management of each stock.

Thus, we can see if we view the fisheries resources of the world as either a source of protein or simply as a raw material transformable into goods and services for peoples of parts of the world where the fishery resource is the important raw material, that perhaps our present yield criteria are sub-optimal (a situation which is generally recognised, but not acknowledged), and in view of the ineffectuality in terms of man's use of fish resources, many existing regulations and approaches to management are in need of more proximal criteria to provide guidance and strategies in stock exploitation. So as we begin to take a systems view of fishery management we see that perhaps we have not formulated management in broad enough terms. Let us consider management from a broader point of view.

3 THE ROLE OF MANAGEMENT

There is tremendous literature on the roles and objectives of management, and it is quite impossible to recapitulate all of this. Rather, I would like to paraphrase some remarks by Drucker (1969), who, in a recent paper, drew some clear distinctions between the "old assumptions" of the role of management and the "new realities" of the role of management. Although these views are intended to reflect upon the management of the firm, it is clear that they are also applicable, in a variety of contexts, to the management of fishery resources.

Drucker begins by observing that "... all institutions will have to make fulfillment of basic values, beliefs, and proposes a major objective of their continuing activities rather than (having) a social responsibility that restrains or lies outside their primary functions. Further, the quality of life is, in fact, a business opportunity and can be converted into profitable business. There should be more emphasis on adapting the institutions to the needs, aspirations, and potentials of the individual than on adapting the individual to the demands of the institution." Entrepreneurial innovation was not formerly intrinsic to management, but now such "... innovation will become the very heart and core of management ... Existing institutions will have to reach out for change as an opportunity, (and) will have to learn to resist continuity." Management should also make knowledge more productive, and Drucker points out, here, that in the production of knowledge, there is no single best way to doing a job and "... there can be no divorce of planning from doing in knowledge work."

Drucker further points out that management should "... be considered as both a science and a humanity." In this respect "... management is ... a culture and a system of values and beliefs and serves as a channel through which society can productively utilize its values and beliefs" and final emphasis is placed on noting that "economic and social development are the result of management."

2/ For recent detailed consideration of nonbiological problems see e.g. the proceedings of the recent FAO International conference on investment in fisheries, or Scott, 1970

Thus, for example, "... there are not underdeveloped countries. There are only undermanaged ones."

At first glance, the new realities of management may seem far removed from fishery management. The new realities are, in fact, far removed from fishery management. The distance between the new realities and fishery management does not arise from any intrinsic property of either the new realities or of fishery management per se. The distance does arise, however, from the attitudes of the institutions involved in resource management and this is why fishery managers have traditionally viewed management from a maximum-sustained-yield point of view which optimizes the yield from a single resource, but essentially leaves the international problems, the political problems, the economic problems, the legal problems, the utilization problems, etc., to the vagaries of chance.3/ Insofar as these other problems lie at the heart of fisheries, it seems, especially if we take the systems view of fisheries, that we should begin to describe our fishery system in terms of all of these problems and the criteria for the way we approach the total problem could, quite appropriately, be set forth in the new realities for management.

Thus, the new realities suggest, with respect to fishery resource management, that the institutions involved in managing, harvesting and processing the resource are accountable for improper allocation of the resource. The best allocation is that which makes the greatest contribution to the quality of life of the individuals that own, 4/ harvest and process the resource.

In order to formulate the mechanisms of accountability we need to consider management from the point of view of the needs of the peoples that are associated with the resource and not from the perhaps crystallized modus vivendi of the existing institutions. The institutions need to become much more dynamic and fluid so that they be responsive to the changing needs. Further, we must consider the resource management to be not only the responsibility of the institutions which traditionally manage the resource but the responsibility of the fishermen and processors as well. All of these people are responsible for progress and innovation. Basically, we need to develop a system of values for our resources.

Thus the role of fishery management basically says very little about the way in which resources should be harvested. Rather it concentrates on developing satisfactory linkages between the people that use the resource and the resource. In order to develop these satisfactory linkages, it is necessary to define the goals of management.

4 THE GOALS OF FISHERY MANAGEMENT

In thinking about goals in general, we generally think of attainment of well-being in some sense, and insofar as one important aspect of well-being is economic, we quite naturally think of economic goals. A suitable set of economic goals might be to attain economic efficiency. Economic efficiency might be interpreted with various shades of meaning. For example, Dorfman (1967) views economic efficiency to include efficiency in distribution, efficiency in production, and consumer sovereignty. Using these criteria, an efficient economy will distribute its resources or production of the resources to the people that need them will fully utilize its resources and place high consideration on the needs of the consumer.

A beginning toward economic goals was stated in the Panel Report of the Commission on Marine Science Engineering and Resources. The idea is that we should judge the production of commodities from fish just as we judge the performance of other industries. In this regard the Panel noted these objectives to be (1) that the marginal cost of production should just equal the marginal value of the project, (2) that the catch be taken at the lowest possible cost, (3) that management should contribute to the invention of new fishing methods and their innovation and finally, (4) that the income from a fishery should be shared by the participants in a fishery and should be no worse than incomes earned in other activities.

Now there are a variety of criteria that might be of use and one which is used in business management is the return on investment criterion. In other words, an entrepreneur has a certain amount of capital which he wishes to invest. How should be invest his capital to maximize the return on his investment?

3/ I fully realize that fishery management is being pursued from a broad point of view considering economic, legal, marketing, etc., aspects of the fisheries. I raise the question, however, whether the views from these various disciplines have been sufficiently integrated and note again, in this respect, that much of the actual practice of fishery management involves the single yield maximization concept.

4/ But most of our fishery resources are not "owned". I am taking the liberty of looking at the futures which indicate the inevitability of ownership sensu latu.

Which investment project, among the available alternatives, should he choose? When should be make his initial investment and how should his investment be distributed in the time stream? These are essentially problems in capital budgeting.

5 MORE PROXIMAL CRITERIA

While the economic goals set forth are undoubtedly the goals that our fishing system should follow, they are, in a sense, overdetermined. That is, saying that we should be more efficient or that we wish to achieve a better distribution of income neither provides the guidance, nor the information on how to achieve these optima. From the point of view of the fishermen and the processor and others that might benefit from the resource, it is evident that a more immediate criteria is that of obtaining reasonable wages and a reasonable return on investment, but even here, as we have pointed our previously, we should specify what we mean by "reasonable", so that our criteria can become operationally useful. We can see that the economic criteria have the potential of being consonant with the roles and objectives of management and it remains for us to determine how they can be applied to fishery problems.

There is a considerable amount of literature on this subject and concise review of the subject may be found in Baumol (1965). Baumol, for example, gives the following capital budgeting model which I have modified slightly to make it conformable with fishery problems:

Suppose we contemplate $i = 1, \ldots, k$ investment projects. The i^{th} investment project could refer to a fishery or to a fishing ground we wish to harvest and our level of investment in the i^{th} project would be denoted by X_i, the number of vessels (say) that we wish to the i^{th} project. Let N_i be the net discounted present value of the expected future returns on a vessel committed to the i^{th} project. mit is the amount of money required to support the i^{th} project during the t^{th} time interval and the total amount of money available for investment in period t is M_t.

It is a relatively simple problem then to choose that level of activities for each project ($X_1, \ldots X_k$) in such a way, so that $\Sigma N_i X_i$ is maximized, subject to $\Sigma m_{it} X_i \leq M_t$ for $t = 0, \ldots, T$ and $X_i \geq 0$ for all i. What is not simple is the variety of assumptions that are attached to utilizing the above model and I will not take space to go into these since they all discussed in the literature. Our main point in presenting the capital budgeting approach is to give an example of a criterion, namely, maximization of the present value of various fishery investment projects. There are, of course, other criteria that can be formulated.

The capital budgeting example is useful for another purpose in that it makes use of the concept of changing values in the time stream. The discounted value is a fundamental property of value-involved orteria and is therefore worth brief discussion. In order to compute the discounted present value of an investment scheme we must consider the cost stream $(m_0, m_1, \ldots, m_t, \ldots, m_T)$ and the benefit stream $(b_0, b_1, \ldots, b_t, \ldots, b_T)$. The discounted present value of an investment scheme is, as is well known,

$$N(I) = \sum \frac{b_j - m_j}{(1+I)^j} \qquad (1)$$

where I is the interest rate which is taken to be fixed and known and undertaking any project with a positive present value will increase the firm's future amount of money.

It would then be quite useful to determine the present value of various fisheries. It would, for example, be useful for the investor because he would want to invest in fisheries with the highest present value and also for the research administrator because he too has finite funds and must guide his research to the most profitable activities which might be adjudged in terms of incremental present value generated by a research scheme.

It might seem quite difficult to compute the present value of various fisheries. Nevertheless, it might be a useful exercise. The first step would be to decide on T, the time horizon. The value of T should be set such that circumstances occurring for $t > T$ are so uncertain that the benefits accrued from including them in the analysis is less than the costs which would be generated by including the events which occur at $t > T$ in the analysis.

The next problem is how to determine the appropriate interest rate. There is no advice for a specific interest rate. The chosen rate should approximate that currently in use in the business community and should perhaps be increased several percent to account for the high risk factors that normally affect fishing operations.

Now given a time horizon and an interest rate, the items that are really interesting are the benefits and costs. Traditionally, we tend to view the benefits and costs from a fishery operation as constants rather than variables. Thus, instead of thinking of costs in terms of deploying a fixed number of vessels and benefits in terms of the per annum tonnage of the catch, it might be useful to think in terms, given our knowledge, of population dynamics, etc.; certain strategies might affect the c_j's and m_j's and consequently the particular N (I) and how this in terms might affect the levels of X_i in our allocation scheme.

Naturally one does not expect to obtain precise values in the above approach, but even approximate values will indicate the sensitivity of the particular problem to parametric changes in the b_j's, the m_j's, I and T, and perhaps offer us some new insights to the data required for management and our management procedures. For example the maximum sustained yield criterion which is in vogue as the management criterion but has been correctly criticized by Gulland (1968, 1969) presents some difficulties when viewed in the context of equation (1). It is quite conceivable under the discounted present-value criteria that we should want to engage in a programme of overfishing in some years and underfishing in other years. The operation of this approach could be governed by maximizing the catch as suggested by Riffenburg (1970).

Thus the capital budgeting concept is applicable to the management of fisheries, and can be consonant with higher level economic goals and can provide more direct guidance to the decision-maker than the economic theory. We wish to emphasize, again, the considerable literature on this subject and that there are other budgetary criteria such as that related to the payback period and the internal rate of return, etc. Many authors feel that of all the budgetary criteria, the discounted present value approach is the most reasonable.

It is also of interest to observe at this point that the conservation of our resources is essentially an allocative process and the calculus that is conventionally used in fisheries is not a powerful technique for allocation. Consequently, our management of fishery resources has been governed by models which have been phrased in the language of differential equations and not in terms of mathematical programming. It would have been interesting to examine the status of fishery management today if the earlier models were allocative - there might not, for example, be a mixed species problem.

6 AN ALTERNATIVE VIEW

We have thus considered a systems view of fisheries management and we can see that it involves defining management in terms of rather broad concepts that would tend to clearly and explicitly interrelate and unify the concept of a fishery as a single complex of social problems, stocks, fleets, processors, markets, etc. But this is essentially a spatially integrative point of view. That is, by our discussion, we have attempted to interrelate elements of the status quo and if we are to truly take a systems view then we must take a broad view temporally as well as spatially of fishery management. This can be attained by use of the subject of technological forecasting.

As indicated in the introduction our technology in general, has undergone tremendous contemporaneous development and in order to minimize the time lag with which our management institutions become responsive to these technological changes it would be wise to forecast technological developments so that the institutions can be responsive to the opportunities provided by the technological developments. In a recent article Bright (1970) noted that "assaying the future" might involve monitoring the technological environment for signals of technological change. These signals arise from events that are closely associated with innovation. Bright summarizes these as follows:

> "... A radical new technological advance is made visible to society first in written words, then in increasingly refined, enlarged and more effective material forms, long before it achieves widespread usage.
>
> The potential impact of the innovation is usually evident years before the new technology is in use on a scale great enough to affect existing societal conditions appreciably.
>
> Social, political, and now to an increasing degree, ecological changes may alter the speed and direction of the innovation's progress, as I indicated previously.
>
> Innovation may be abruptly influenced by decisions of key individuals who control supporting resources or determine policies that affect their application.

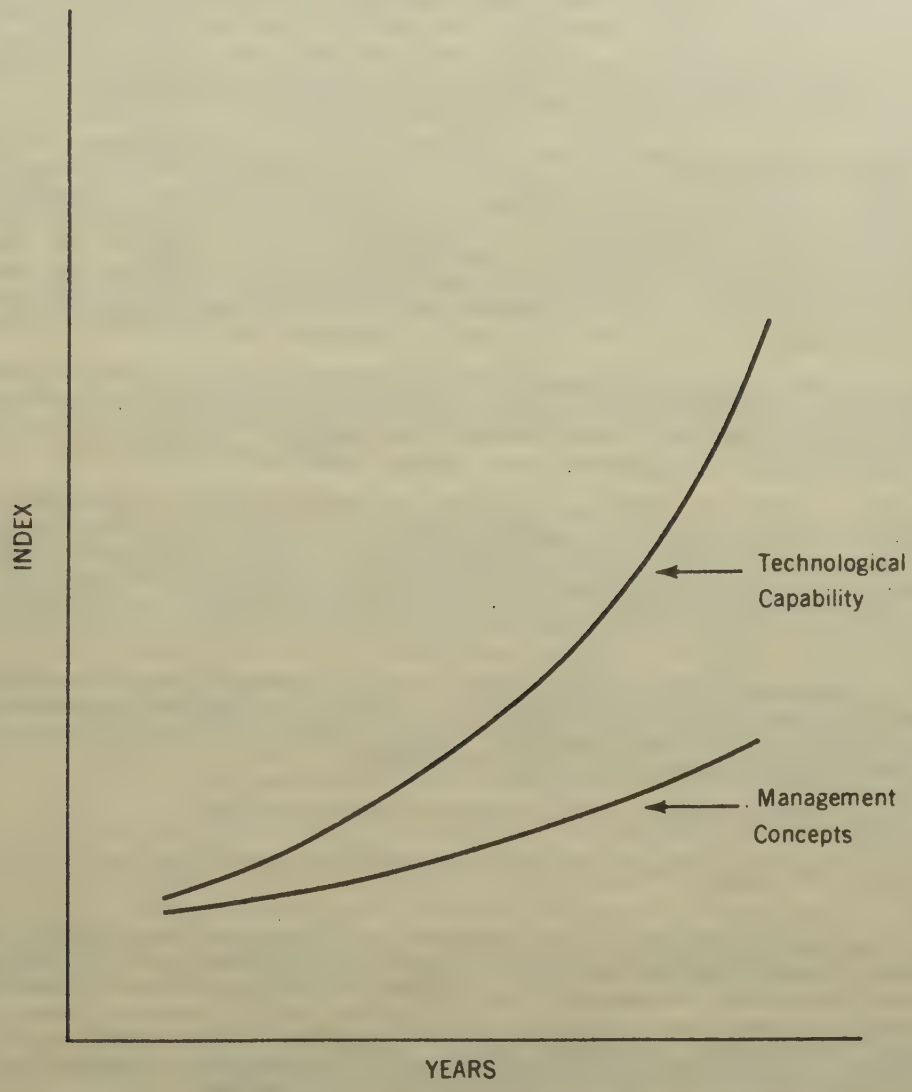


Figure 1. Relation between technological capability and management concepts adequate to fully utilize the technological development.

Technological capabilities - e.g., parameters such as speed, power, miniaturization, strength, and capacity - increase exponentially over time, once bottlenecks are broken ... but it will begin to level off if they encounter scientific, economic, or social barriers..."

As we consider how technological change might affect fishing we should keep in mind another important concept and that is the general relation between management - the subject of this paper - and technological change. 5/

This relation is depicted in Figure 1, which shows that in general, technological capability is developing at a much faster rate than our management concepts. For a general example, our technological capability to transport people has far outstripped our ability to develop management concepts which transport people in an efficient manner. In other words, hardware has reached a much higher degree of sophistication than software in terms of development. For a more specific example consider that our technological ability to catch fish far excels our ability to manage the stocks.

Fisheries technology and management, just as in the general situation, present an evergrowing hardware-software gap, and we can forecast that this gap will, especially if we continue to take the narrow view of fishery management, grow fantastically large with the progress of time. This is because the hardware and technological capability that we ordinarily ascribe to fisheries in terms of boats, nets and gear are much too narrow. The field of fisheries has, in fact, access to the technological capabilities of undersea vehicles, tremendously sophisticated acoustic and other underwater communication devices, computer technology, etc. Yet the managers associated with the fisheries have not transformed these technological capabilities which are, in terms of fisheries, into innovations in the fishery field.

It would seem that forecasting of technology in fisheries must recognize that the most likely impact of technological advance will be the use of already developed hardware in fishery problems. It will not be possible to simply decree the use of this hardware, but rather it will be necessary to take a systems approach to the application of this hardware using highly trained specialists.

So not only will we have fisheries develop, primarily by increasing the hypothetical index of management concepts to meet technological capability, but also along certain lines for which there are ample technological signals. Using Bright's criteria in terms of the technological signals and optimism that fisheries managers can reduce the management - technology gap - largely by increasing management capability - I have forecast the technology of fisheries that looms just beyond the horizon, (Rothschild, in press).

"....as we view fisheries in the context of the '70's,... we have not been establishing the right criteria concerning the growth of our fisheries. If we do not have the right criteria, then we have no hope for asking the right questions. I think that we have been too concerned with describing the status quo rather than probing the future.

In thinking of the fisheries of the future, we need to think of

(1) Fleets that are highly mobile and are able to fish anywhere in the world. Such fleets already exist.

(2) Fleets that are modular in the sense that if purse seiners or certain refrigeration or processing capabilities are needed, these can be taken off the shelf and plugged into a particular expedition as required. The concept of modularity is a very useful device in constructing systems because a modular construction usually exhibits a lower cost structure, increased reliability, and greater ease of management than non-modular systems. A modular fleet will require a new attitude toward fisheries, re-design of equipment and a much larger management unit than presently exists for most U.S. fisheries.

(3) Fleets that exert tremendous amounts of fishing intensity. Such fleets are also already in use. The advantages of fleets that are capable of exerting tremendous fishing intensity are coupled with mobility and modularity so that a high intensity pulse of fishing effort can make most effective use of the fish stock and of capital equipment. In general, we should like to harvest the fish at the "instant" corresponding to the point when it reaches a peak

5/ This concept was brought to my attention by George Rounds of Temps Incorporated

biomass (we are assuming, to simplify our discussion, that harvesting at the peak biomass is economically optimal, an assertion, which is, of course, not necessarily true). Suppose we could harvest this optimal yield from a stock in two weeks; we have then picked the fish when they are "ripe" and our fleet is free and capable, but virtue of its mobility and modular construction of moving elsewhere and fishing.

(4) An entirely new approach to refrigeration or preservation or processing will be required. Because of the tremendous catching power of the fleets, it will be necessary to hold fish in a preserved state until they can be processed. This new technology would probably need to be quite radical since huge quantities of fish would need to be processed in a relatively short time.

(5) Development of concepts of ownership. The course of events in today's fisheries is such that the catch from a stock might be reduced 10-fold and decreases in effort would result in increases in yield. The "tragedy of the commons", however, prevails and there is little advantage to reducing effort, so the fishery moves to adjacent stocks and in so doing the catch today is 50 percent rather than 10 percent of its former magnitude. It appears that the principle of ownership of fish stocks will be required so that these stocks can be effectively utilized. It makes little sense to talk of effective utilization without effective management and effective management is most hopeless without some concept of ownership. The development of ownership poses some rather enigmatic questions because its development places an obvious constraint on the mobility and other degrees of freedom that will be characteristic of the fleet of the future.

(6) The use of foreign sources of equipment and capital. This is already done in other industries. A modernization of our equipment, in general, may not be sufficient to make fishing profitable. The cost-price squeeze requires examination of foreign labour for construction, repair, maintenance and even fishing.

(7) The development of a fishery information system. The fishery information system is computer based. It will store the time-space trends of fish abundance for all major stocks of fish in the world and similar trends for the minor but relevant stocks. At the end of each day's fishing, the catch, oceanographic, and meteorological data will be radioed to the computer. The computer will then advise the skipper his optimal strategy for the next day's fishing. The computer might even give the skipper a choice of strategies with the probability that each will pay off. Since the fleet is modular and mobile, the choices can be very wide. (The savings in the acquisition of ocean and weather data alone will be quite large.) At the same time, a processor can inquire of the computer system and find out the expected time of arrival of a load of fish because that information will be radioed to the computer by the skipper. The system will, since it "knows" the amount of fish landed and still aboard boats at sea, and also the landing trends for other years will be able to predict for the processor the nature of landings, days, weeks, and months in the future. The system will have an interesting device so that it will not give out information that would be competitively unfair until that information is competitively obsolete; an amount of time which might in some instances be measured in hours or days and in others months. Instead of managing a stock by setting a size limit or quota at the beginning of the year, management will be prosecuted with the aid of the system on a virtual real-time basis. In addition to all of these things, the computer will aid in capital budgeting, accounting, and day-to-day management systems of the firm or firms which utilize the system.

It is fairly obvious that the technological changes described above will not just happen. The effectuation of these changes requires stimulation from the community of individuals in the fishing industry. The problems that need to be attacked are too large to be undertaken privately; they need to be undertaken by government.

Such changes will basically result in aquaculture. Not the aquaculture that we traditionally think of, but an aquaculture of the sea where stocks are harvested as efficiently as in some of our more sophisticated agricultural techniques."

We can say that of the various technological signals that we have discussed, there is one that appears particularly strong and that is the computer. Computers are of course at a high degree of sophistication but are not in wide use in fisheries or in the development of the integrated management information system that we described earlier, to relay fishing strategies to the fleet, to provide information to the processor and to aid in more or less conventional management. We should not,

however, be surprised at the lack of computer aided management in fisheries because such a situation evidently existed in industry until only recently (Vandell, 1970). The reasons for this computer gap in industry have been manifold, according to Vandell, and understanding these constraints as they existed in industry may enable us to obviate the same constraints in fisheries. These involved the lack of trained manpower with well developed computer skills, a lack of understanding of the power of computer applications by executives and top decision makers; and a lack of software without which experimentation within an organization tended to be discouraged. These constraints are now apparently on the verge of being completely eroded in industry. We can consider that these constraints also apply to the problem of managing fisheries but they are nowhere near eroded away, and this is testified to by the rank confusion in which much of the world's simplest fishery data exist, let alone sophisticated management systems.

There is no question that if fisheries of the future are to conform to the above mentioned scenario that a computer oriented information system will need to be developed and fortunately there are concepts in the literature on information system development. In contrast to the more or less philosophical concepts on the role and goals of management, the concepts involving the information system tend to be, perforce, operational.

But just as we took the broad view of the philosophical approach, we should consider the operational aspect of management from a broad point of view. One such view is developed by Anthony (1965), who notes that:

(1) The starting point in construction of the over-all system should be management control, which deals with the ongoing operation of the whole enterprise.

(2) The management control system should be related to, but should not include, the processes for strategic planning, operational control, and financial accounting; the notion of a single all-purpose system is unrealistic.

(3) The central management control system should be a financial system since money is the only common denominator.

(4) Computers and mathematical models cannot be the essence of this control system.

At this point we can see, from Anthony's framework and his subsequent discussions, the evolution of some concepts applicable to the design of a fishery-management information system. The most important is that the activity of management is not monolithic, it should be considered in terms of high-level policy, strategic control; a tactical view, management control; and a day-to-day functioning, operational control. In relation to fisheries, we can then view the strategic control as the area in which fishery management institutions, fleet owners, resource owners, and processors set philosophy on regulation, species mixtures, etc. The management control is not fishery management *per se* but tactical control allocating, for example, vessels to catch fish in time-space coordinates and finally the operational control governs day-to-day vessel operations, etc. It is interesting to observe that if we view fishing as an integrated enterprise of fishing, processing, and fishery management, then we have a rather interesting paradox in the sense that from the traditional fishing management institution point of view, management focuses on the strategic aspects, yet most of the "action" in fishing is concentrated on the tactical and operational aspects, and, at any rate, there do not seem to be effective communications among the various levels. Thus, from these points of view fishery management is perhaps emphasizing the wrong aspects of any problem.

As an alternative to the existing management approach in fisheries we might indicate some ways of thinking about management from a strategic, tactical, and operational point of view. We will consider the strategic point of view in terms of existing management structures and then the tactical and operational problem. We will also consider the effect of considering the tactical and operational problems upon the strategic question.

The existing management structures involve consideration of essentially three conceptual approaches. These are the yield-per-recruit approach, the stock-production approach, and the stock-recruitment approach. These have been discussed in considerable detail in the literature and there is no need to replicate this discussion. There are, however, some points of detail that seem to be worth mentioning in connexion with tuna fisheries and possibly others as well.

First, the yield-per-recruit approach can now, with the aid of various tables (Beverton and Holt, 1966, Wilimovsky and Wicklund, 1963), be computed under a considerable variety of conditions. Various computer algorithms are available to not only compute the most often used Beverton and Holt yield isopleths, but Ricker's (1957) approach or any more or less arbitrary arrangement of growth and mortality over various intervals of the organism's life. In order to show the flexibility of this approach, we compare, using the Paulik and Bayliff (1967) computer algorithm and SYMAP plotting routine (see e.g. Rothschild et al.,1969), yield-per-recruit isopleths for a fish subjected to a 3 month and a 6 month fishery and the residuals between these two strategies. The appropriate life history details are outlined in Table 2. We can see from this particular example that the strategy of a 3 month season is always better than that of a 6 month season except at low selectivity size and high fishing effort. The point that we wish to demonstrate is that virtually any time-variable assumptions on mortality and growth can easily be incorporated in a yield-per-recruit model with the aid of tables and computer routines. In fact, in most instances, data will not be available to meet the full flexibility of the computational opportunities.

The second concept involves production models which are of fundamental importance in the management of fisheries. These models generally require only catch and effort statistics and do not explicitly require that the fish under study be aged. Tunas are notoriously difficult to age but catch and effort statistics are generally available and so production models have wide applicability to tuna problems. The main point to be made is that production models tend, owing to their relatively limited data requirements, to be simple. This simplicity tends to be superficial and misleading, however, because it is sometimes difficult to ascertain the extent to which the assumptions involved in the general production model are met. Because of their widespread use in tuna dynamics - I will briefly review the nature of these models and a few problems dealing with the assumptions of the models.

Schaefer (see, for example, Schaefer and Beverton, 1963) was the first to use a production model to develop management strategies for the yellowfin tuna fishery of the eastern tropical Pacific Ocean. The basic idea is that the rate of change of the population is

$$\frac{dP}{dt} = \phi(P) - fqP \qquad (2)$$

and equilibrium catch is clearly attained when fqP is adjusted so that $fqP = \phi(P)$. If we let $\phi(P)$, as is customary, be a parabola, then we have in Pella and Tomlinson's (1969) notation $\phi(P) = HP^2 - KP = H\left(P^2 - \frac{K}{H}P\right)$ where $\frac{K}{H}$ is the maximum biomass. This may conveniently be plotted as a linear function $c/qf = K/H + (1/H)\,qf$ so that we have intercept $\frac{K}{H}$, and $\frac{1}{H}$ then is $\frac{d(c/qf)}{df}$ or rate at which the population declines per unit of fishing effort.

TABLE 2

Data used for yield-per-recruit calculations

Age (Years)	Corr. Length	Corr. Weight	Inst. Growth Rate approximated from VBGF L_∞ = 198, K = .28	Inst. Natural Mort.
0	0	0	1.2285	0.200
3.21	121	1 450	0.5319	0.208
3.68	131	1 862	0.4202	0.239
4.23	141	2 346	0.3309	0.239
4.88	151	2 910	0.2985	0.317
5.69	161	3 559	0.1774	0.492
6.76	171	4 302	0.1140	0.733
8.33	181	5 143	0.0571	1.138
11.29	191	6 090		

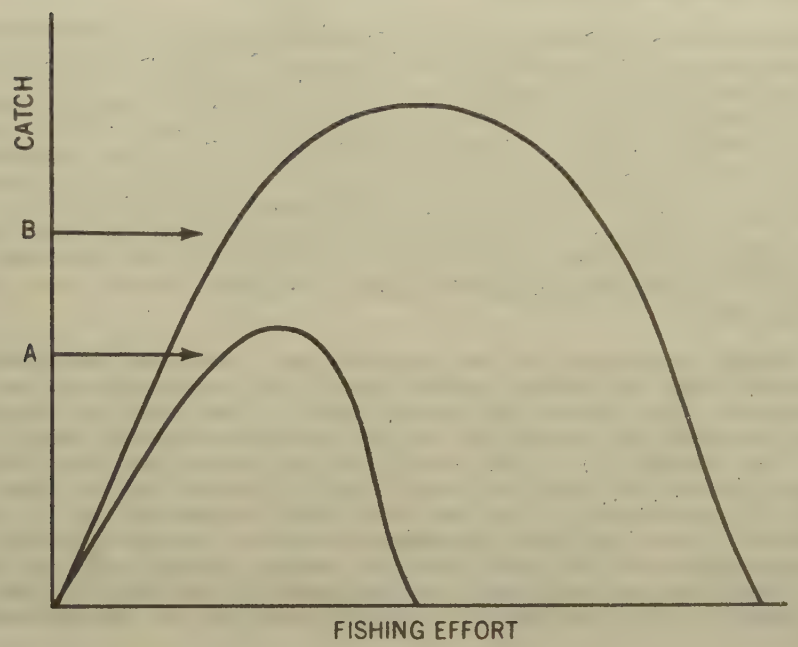


Figure 2. Relation between catch-effort curves when fishery expands from a smaller effective population (A) to a larger effective population (B).

The approach used by Schaefer was generalized by Pella and Tomlinson (1969) to yield, in general, a curvilinear relation between catch and catch-per-unit-of-effort and asymetrical relation between catch and effort. Schaefer's approach is a special case of the Pella and Tomlinson presentation. Their generalization was obtained by letting $\phi(P) = HP^m - KP$. Fox (1970) examined the problem under more restricted circumstances. An interesting discussion of the behaviour of a stock as it approaches equilibrium may be found in Chapman et al. (1962). Equilibrium conditions can also be approximated as shown by Gulland (1969), by plotting catch-per-unit-of-effort against effort, using the average effort to which the fish has been exposed during its life in the fishery.

As indicated previously, the simplicity of the production model may be misleading. As an example, we need, explicitly, only catch and effort data. But implicitly we need to know, in addition, that effort is measured in units proportional to fishing mortality. Thus, in addition to information on fishing effort we also need to know that the catchability coefficient either is not changing, or if it is changing, then we need to know the nature of the change. Although the problem of the proportional relation between nominal fishing effort and fishing mortality has been the subject of various symposia (e.g., see Gulland,1964), it is not clear that this problem is generally recognized by practitioners who use the general production approach.

To emphasize this point we repeat that a fundamental assumption in these methods is that the relation between nominal effort and catchability be constant over the series of data on hand. Basically c/f is used in a production model to provide an index to the number of fish per unit area. In order for a set of c/f indices to accurately reflect the magnitude of the change in the number of fish per unit of area, it is necessary that f be measured in the same way for each c/f datum. This can be stated more precisely (following Gulland, 1969a) by noting that the instantaneous rate of fishing mortality in the i^{th} year is equivalent to $F_i = f_i \left(\frac{q}{A_t}\right)$. We conventionally assume that the term in brackets is a constant for all i, and redefine the bracketed term as q' so that $F_i = q'f_i$. Thus it is implicit that q, A, and t must all be constant for each f_i; if q, A, and t are not constant then changes in c_i/f_i may not adequately reflect changes in the population and the employment of such c_i/f_i's in a production model may then generate management suggestions which could be quite costly in either a real or opportunity sense.

While some changes in catchability are rather obvious, resulting from direct changes in gear such as that which occurred when the eastern tropical Pacific yellowfin-skipjack tuna fishing switched from bait-boat to purse-seine gear, others may be more subtle in the sense that changes in the method of fishing resulting in changes in catchability may be difficult to either record or detect. Consider one possibility as an example: It is well known that the typical tuna longline bait is the saury. The Japanese-Russian catches of saury were quite large in the mid 1960's. These catches have, however, declined rapidly. It is unlikely, at the same time, that the average size of the saury in the catch has declined. There are also reports of increasedincidence of substitute baits. It is thus quite likely, owing to the decline in the saury stocks and events related to the decline that catchability in the longline fishery has been modified. The importance of this modification, if it has in fact occurred, again depends on the magnitude of the modification and the circumstances.

But even without direct modifications to the gear, changes in the catchability can arise in what are perhaps more subtle ways, especially in the context of general production models, by the fishery changing its areal distribution.

Let us consider several examples. First, if the fishery area increases (a situation which commonly occurs in tuna fisheries as perhaps typified by the expansion of the Japanese tuna longline fishing in the Pacific Ocean (Rothschild and Uchida,1968)) and the population size remains constant, then the catchability q' will decline. On the other extreme, if the fish are relatively immobile then as the area increases the effective population size could increase, but catchability might or might not change. We might view what might happen under the situation where the effective population increased but catchability and the other parameters remained constant. This is plotted in Figure 2. Curve A represents the catch-effort relation for the "old" fishing area and curve B represents the catch-effort relation for the old plus new fishing area where the individual fish tend to be relatively immobile. It would not be unreasonable, for a first approximation,to consider that the increase in the maximum size of the total population is proportional to the increase in the fishing area. It is also quite possible for catchability to change directly as the area of fishing changes. For example, contrast the previous example where catchability remained constant, but as the fishery expanded the effective "population" increased by virtue of the relative immobility of the fish with a situation where the fish may be relatively mobile but exist in a gradient of fish density. As the fishery moved into higher and higher densities the catchability would then increase. Actually both types of mechanisms are likely to operate as the fishery changes its areal extent. Even if it were possible to sort out the effects of increasing population size from changes in catchability it would be difficult to assume, for example, that the progression of the fishery would not eliminate the density

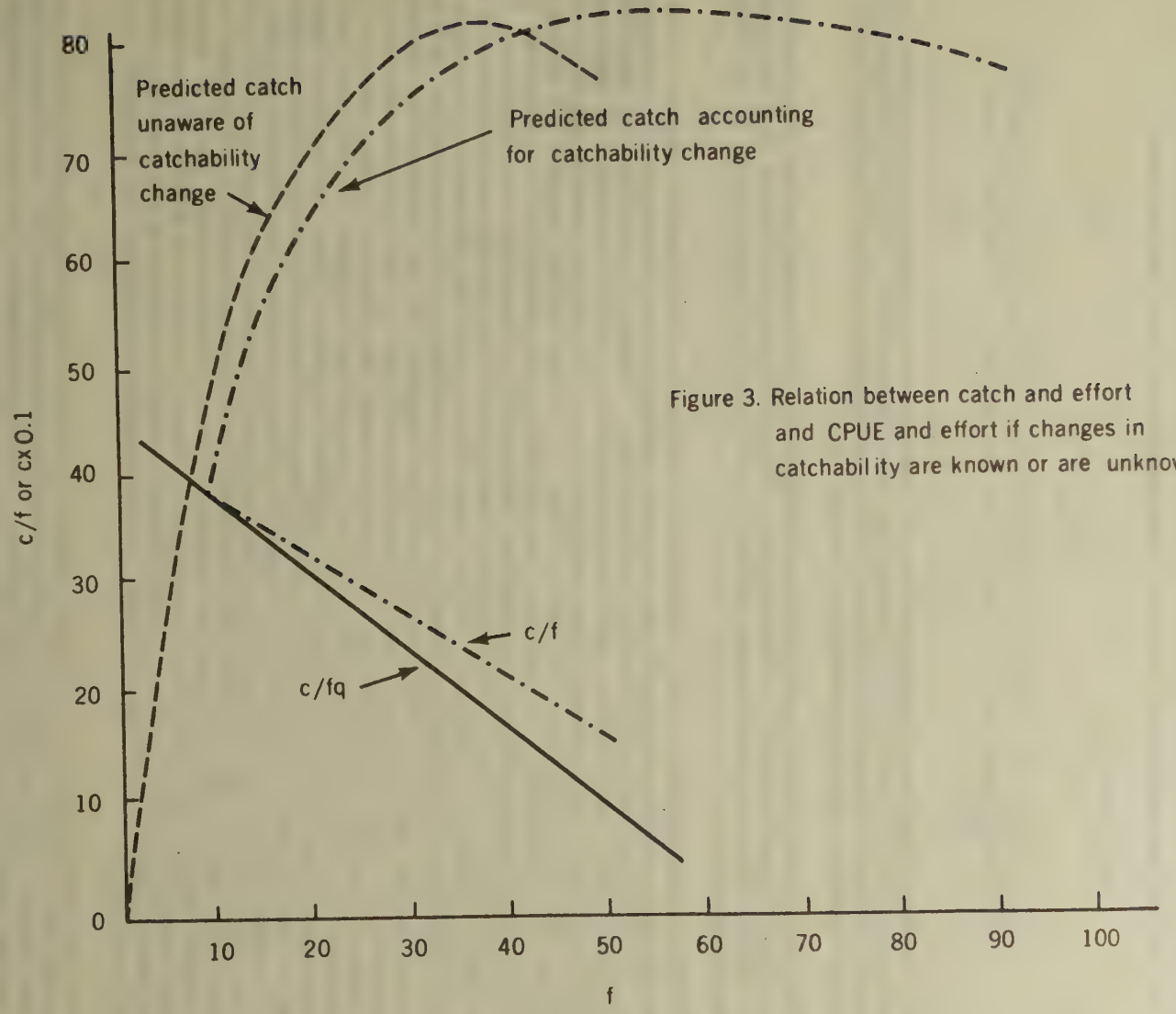


Figure 3. Relation between catch and effort and CPUE and effort if changes in catchability are known or are unknown

gradient and catchability would return to its original level.

These difficulties can be expressed more analytically by considering the old fishing region to have an area A and the new region to have an area a. The catches from these regions are related by the known constant k, using the usual notation,

$$F_A N_A = kF_a N_a \qquad (3)$$

so if we let q be the catchability in A and p the catchability in a, we can write,

$$qf_A N_A = kpf_a N_a \qquad (4)$$

Thus,

$$\frac{p}{q} = \frac{f_A N_A}{kf_a N_a} \qquad (5)$$

We have, however, a problem of identifiability, so taking one option if we wish to assume $N_A/N_a = A/a$, we can estimate p/q by plotting $kf_a N_a$ against $f_A N_A$ which should yield, if p/q is constant, a straight line passing through the origin with slope p/q. On the other hand we could assume p/q to be 1 and estimate the relative densities which are, of course, just k.

Thus, it is clear that we need additional information to understand the relation between p, q, N_A and N_a. This information might be obtained from a tagging experiment and would lead to discerning whether a model accounting for increased population size would be appropriate or, on the other hand, increased catchability.

We have already pointed out the consequences of increasing the effective population size in the general production setting and it will now be useful to examine the consequences of increasing catchability. Catchability can be modified in a number of ways. Perhaps the most typical modification is an increasing trend in catchability. Such an increasing trend can be important. If this trend is unidentified a fishery could behave in an inexplicable way. In order to demonstrate this problem we have constructed a hypothetical set of data in Table 3. In the table we present, for reference, a set of data for which catchability is constant. We then modify the catchability by arbitrarily increasing its value as effort increases(strictly speaking, catchability reflects the relation between fishing effort and the number of fish in the population whereas production models usually relate the weight of fish in the population to effort.) We view these data in which the catchability increases with effort in two ways. In the first, we take into account the change in catchability and in the second we can pretend that we did not know that catchability increased. We are interested in comparing the conclusions from the two models. We have plotted these in Figure 3. The figure shows that c/f uncorrected for a change in catchability will underestimate the affect of fishing upon the population. We can also see that where the true c/fq will yield a symmetrical relation between catch and effort, the uncorrected data will yield an asymmetrical catch-effort curve. Thus, the degree of symmetry or asymmetry might relate to an inability to properly measure effort and not reflect any intrinsic property of the population which might be implied by fitting a general production type of model. The relation between catch on the correct and on the incorrect effort scale is also shown in the figure. We can see that if we do not recognize that catchability is changing we will at relatively low levels of effort obtain catches that are less than predicted, but at relatively high levels of effort we will obtain a catch greater than that which is predicted. The way in which we modified catchability was, of course, arbitrary, and so we can see that undetected modifications in q could greatly affect the relation between normal effort and catch and in some management situations the magnitude of this error might be important.

It is, in this connexion, of further interest to pursue a simple implication of the symmetrical yield-effort curve which is implied by a linear relation between CPUE and f. This relation was used in another context in our "Report of the meeting of a group of experts on tuna stock assessment (Under the FAO expert panel for the facilitation of tuna research)" which was held in Miami in August 1968. The implication derives from observing, in the usual notation, that

$$C = \frac{fq}{fq + M} R \qquad (6)$$

TABLE 3

Hypothetical data showing the relationship between effort and expected catch when catchability is constant and when catchability increases with effort

Catchability constant				Catchability increasing			
f	q	c	c/fq	q	nominal c/f	catch	f=fq
10	1	380	38	1.0	38	380	10
20	1	610	30.5	1.033	31.5	630	20.66
30	1	690	23	1.130	26	780	33.9
40	1	624	15.6	1.282	20	800	51.3
50	1	400	8	1.875	15	750	93.75

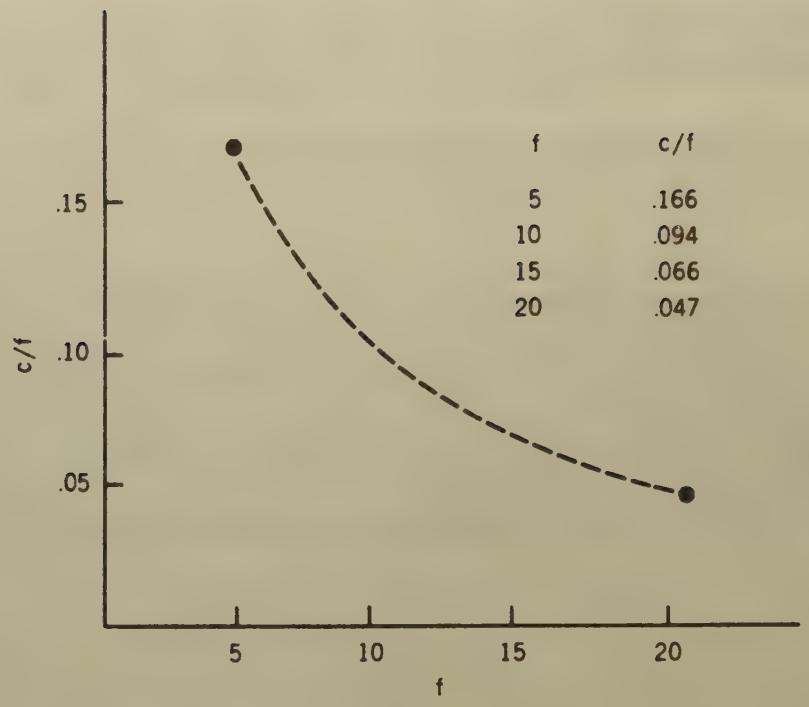


Figure 4. Relation between CPUE and effort when R, q, and M are constant.

from which we obtain

$$\frac{f}{c} = \frac{1}{R} f + \frac{M}{Rq} \qquad (7)$$

Thus if we plot f/c against f, we should, if R, q and M are constant, have a straight line with intercept M/Rq and slope 1/R. These are of course the usual steady state conditions. But now, in the context of our discussion, it is of interest to determine with these conditions of constant R, q and M the implications of plotting c/f upon effort with R, q and M constant. We can obtain from either (6) or (7)

$$\frac{c}{f} = R \frac{q}{fq + M} \qquad (8)$$

which we can immediately see is not linear by taking the derivative of the right hand side. So if we take some simple values of f, and set R = q = M = 1 and plot c/f as a function of f we have a curvilinear relation plotted in Figure 4. Thus for those situations where a plot of CPUE on f is linear, q, M and R are not, in general, all constant which may contradict some of the fundamental assumptions of the production models.

Thus we can see that two factors are generally quite important to utilizing production models for management purposes: the possibility of undetected, but more obvious changes in catchability and the less obvious changes in the effective population and the mobility of the fleet vis-à-vis the fish.

While the fact that catchability changes is obvious, it is often not quite so obvious how it changes. One technique that might be useful was developed by Rothschild and Robson (MS) and is based on the concentration index which was suggested by Gulland (1955) and used in tuna work by Calkins (1963). The index, which is the ratio of the ratio of averages CPUE to the average of ratios CPUE statistic. This index has the unfortunate properties of (1) being difficult to interpret, (2) does not contain all of the information in the data, (3) is asymmetrical and has no upper bound. When the index is greater than 1 the fishermen are "concentrating on the fish", less than 1, they are not concentrating on the fish, and equal to the fish, fishermen distribution is random. Rothschild and Robson noted that since

$$\left[\frac{\frac{1}{n}\Sigma c}{\frac{1}{n}\Sigma f}\right]\left[\frac{1}{n}\Sigma\frac{c}{f}^{-1}\right] = 1 - E(c) - E(c/f)E(f) = 0 \qquad (9)$$

the correlation coefficient between CPUE and effort might be a better alternative index since the correlation coefficient is symmetrical about zero, is bounded between -1 and +1, might be interpreted probabilistically, and is easily interpretable.

Another technique that might be of some use in discerning the relation of the distribution of fish relative to that of effort and catch was used by Rothschild and Yong (1970) in their study of albacore distribution in the Northwest Pacific. They considered the spatial moments of catch-per-unit-of-effort, catch, and effort. It is clear that the distance between the first moments of CPUE and E, for example are a measure of the efficiency of the fleet and any temporal change in this statistic reflects a difference in operation that could produce changes in the catchability coefficient.

Another problem that could result in differences between observed catches and expected catches in a production model is that production models give the expected catches in terms of populations that are in equilibrium. Insofar as data from populations are essentially in equilibrium might be used to predict catches for populations in disequilibrium, and data from populations in disequilibrium might be used to predict catches from populations in equilibrium, errors could be induced in providing management advice. Perhaps the most important cause for disequilibrium in a fishery is the occurrence of strong year classes. Thus errors will be induced if data "in equilibrium" are used to estimate "equilibrium catch" for time intervals when there are no strong year classes.

A critical problem could arise if catches are greater than predicted owing to strong year classes, then there would be an inevitable clamour to increase the amount of fishing effort which might be undertaken by the construction of new vessels. The strong year class would, however, disappear from the fishery and the fishing operation would be in danger of over-capitalization.

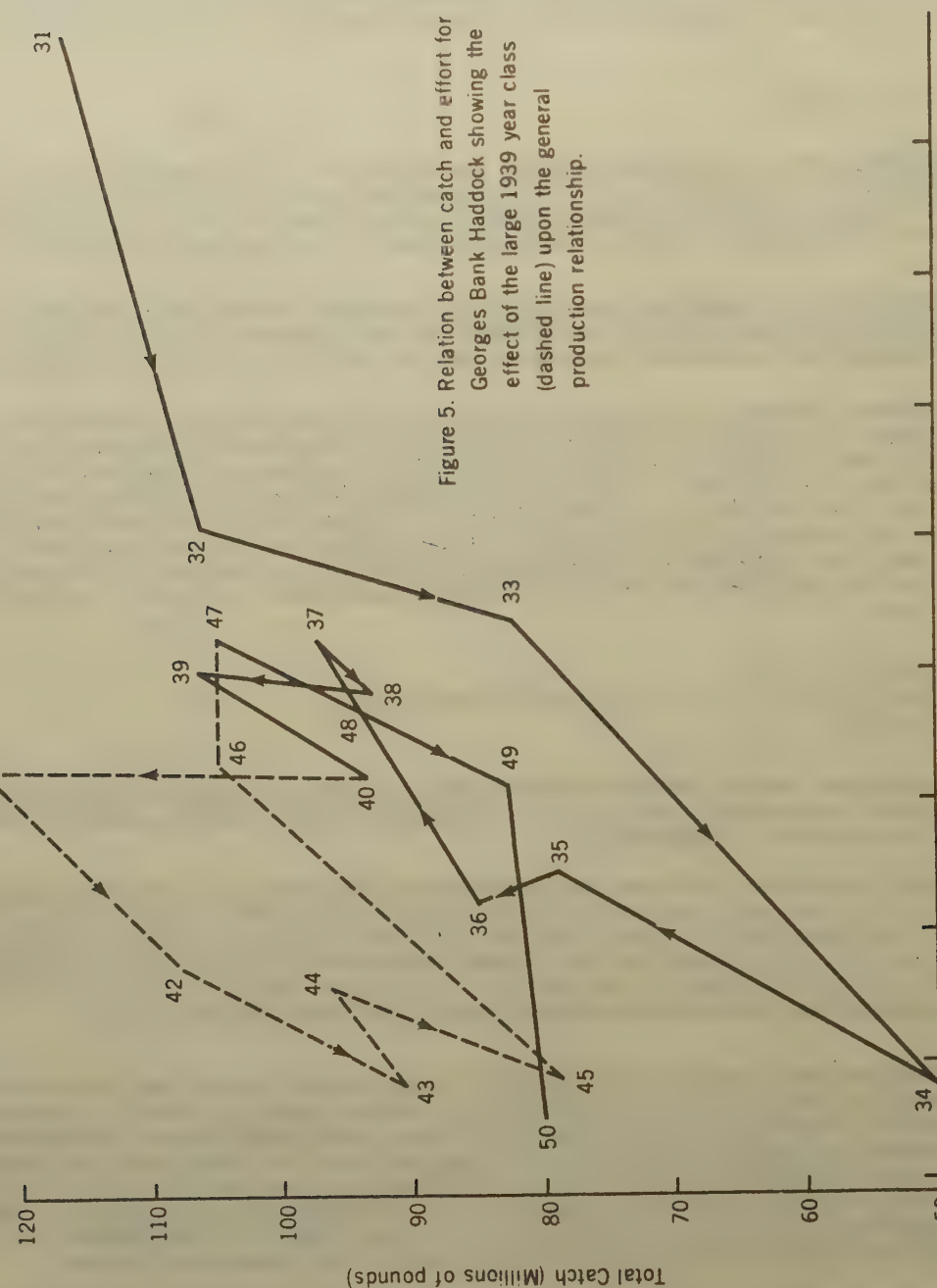


Figure 5. Relation between catch and effort for Georges Bank Haddock showing the effect of the large 1939 year class (dashed line) upon the general production relationship.

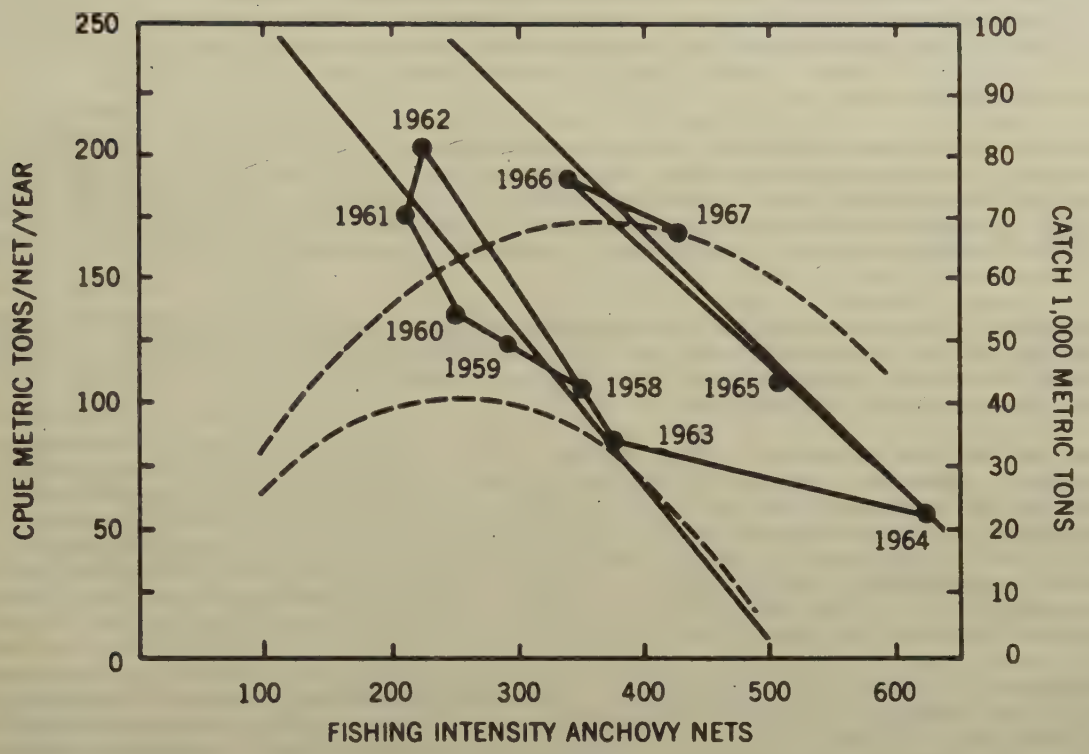


Figure 6. Regression of CPUE on fishing intensity and the total catch on fishing intensity for the anchovy in Korean waters.

To illustrate how this effect might operate, I will utilize the catch and effort data on Georges Bank haddock, which were presented by Royce and Schuck (1954) Table 4. These data include effort and catch statistics by age group for the years 1931 to 1950 and demonstrate the presence of the large 1939 year class which was evident in the fishery from 1940 to 1948. I have plotted these data in Figure 5. It is not necessary to fit an equilibrium yield curve to these data to see if we were unaware of the existence of the large year class and fit a curve to all of the data we would arrive at a different catch-effort relation than if we excluded the large year class from our computations. The presence of an undetected large year class might lead us to expect, depending upon the degree to which we are in an area of the curve which is extrapolated, to err, possibly seriously, in estimating yield from a given effort.

This example was chosen to demonstrate the effect of abundant year classes on the production model where it is known that these abundant year classes actually do exist. For most tunas age data or year class data would not be available. This would be particularly true for the more tropical tunas, but for these relatively short-lived fishes the effect would not be as great as that for the haddock which remain in a fishery for several years. On the other hand, the more temperate albacore and bluefin could be in a fishery for several years; there is some reasonable possibility, however, that the more temperature tunas can be aged.

Other subtle effects can contribute to misinterpretations of production curves. For example, changes in gear selectivity can contribute to changes in age structure in the population and consequently to changes in equilibrium yield. This is easy to see intuitively because in the conventional yield-per-recruit model, we can alter yield-per-recruit by modifying the size-at-first entry. A possible example of such a situation may be evident in the anchovy stocks taken in Korean waters (Marr and Rothschild, MS).

This is shown in Figure 6 where we have regressed CPUE on effort measured in terms of standard anchovy nets before 1963 when the fishery was prosecuted predominantly by power drags which took large numbers of quite small fish and after 1963 when the fishery was prosecuted predominantly by gill nets which took larger fish than the power drags.

We can see then that the accuracy of production models in fisheries dpends upon the relation of nominal effort to true effort and again we will not belabour this point because it is covered in considerable detail in Gulland (1964) and other places. The question of whether errors in effort calibration affect accuracy seriously really depends, however, upon the use for which the data are intended. If the data are actually used in management then the questions we are discussing are quite important and measurable in either the value of the fish which are not taken and could be taken because of "under-fishing"; by the fish which are lost to the catch by "over-fishing"; or in terms of the additional effort required to take a fixed catch under conditions of "over-fishing".

Thus in some circumstances the measurement of catchability might be exceedingly important and it is useful to have estimates of f which do not depend on nominal effort. These can be obtained in a variety of ways such as using Murphy's (1965) iterative solution of the catch equation, use of virtual populations, or by tagging studies. Both the virtual population and iterative solution of the catch equation methods were used by Davidoff (1969) to study the yellowfin tuna in the eastern tropical Pacific.

Each of these methods has certain drawbacks. The tagging procedure is expensive and involves difficulties such as tag loss, but again the expense must be judged relative to the value of the information that would accrue if alternative approaches were attempted. Instead of using a recovery per unit of effort type of approach which would require estimation of effort we might use, for example, the Seber-Jolly (see, e.g. Seber, 1962) which would give us the probability of capture from fishing. The conversion of these probabilities to instantaneous rates is available in some of the demographic literature but not in fisheries literature. The method of deriving these conversions is outlined in Rothschild (1967).

The procedures involved in using either the iterative solution of the catch equation or the virtual population methods tax most tuna data since again it is difficult to obtain the catch in numbers of each age class. The iterative solution of the catch equation has been generalized by Tomlinson (1970) who has discussed the problem of bias in the method. It would be interesting to introduce an error structure in this method and study its behaviour using Monte Carlo techniques. The virtual population approach has been discussed by Fry (1949), Ricker, Bishop and others. The idea is that fishing must account for a large proportion of total mortality, because if this is true, the approximation

$$E \tilde{=} 1 - e^{-z} \qquad (10)$$

will be reasonable and since fishing accounts for a large proportion of total mortality, the further approximation $z \tilde{=} F$ should also be reasonable so from this we deduce

$$F \tilde{=} -\log (1 - E) = F' \qquad (11)$$

Owing to the nature of the approximation $F' \geq F$. If we can assume that F' is proportional to F, then at least the relative changes in catchability could be deduced which would enable standardizing effort to a standard year. Again, the estimation of catchability is a difficult problem using the available techniques. We can see that the available techniques for estimating catchability leave something to be desired, especially for those fish which are as difficult to age as the tunas. It would seem that another approach might be more applicable and this approach would involve an analytic study of fish behaviour and fish-gear interaction to construct a model which would predict the fraction of a population taken by a particular unit of effort deployed in a particular way. In other words, catchability would be estimated almost immediately by knowing how the gear is deployed rather than by hindsight, waiting for several years of data to accumulate. As an example of the very simplest use of such a method consider, in reverse, the "swept-area" approach for estimating population size.

The final existing management concept that we shall briefly discuss is the stock-recruitment problem, a problem which has been a serious occupation of fishery biologists, and subject of a symposium in Aarhus in August 1970. First of all, the stock-recruitment problem is usually attacked by plotting some index of stock size against some index of recruitment. The result is usually a cloud of points exhibiting little correlation. Then one of the usual stock-recruitment relationships is fitted to these data. It may be of scientific interest to continue to plot these relationships ad infinitum, but if we were to take the systems view we would make two observations. First, we would say that the stock-recruitment problem is overdetermined and not well defined. That is, the stock-recruitment system consists of many sub-systems which have not even been defined. These sub-systems consist of components that involve the behaviour and physiology of the larvae (possibly the adults as well) and while there is not a voluminous literature on this subject, there is a large amount of material, that, as far as I am aware, has not been brought directly to bear on the relation of stock and recruitment to predicting the abundance of year classes. Secondly, we ask what is the function(s) of studying stock and recruitment and how do the studies fulfil these functions. The function is obvious but it is questionable whether present techniques can be helpful. It appears to me that this is specially so in the tunas. The existent approaches at the strategic level, then tend to concentrate on using yield-per-recruit, general production, and stock and recruitment techniques. It is clear that a broader view of the strategic problem should directly acknowledge the problem of allocating multiple stocks to multination fisheries and that the several nations will need to consider strategies for allocating these stocks to the firm or firms which comprise their fisheries. There have been several schemes which have been proposed from time to time which suggest various allocation policies involving licensing and other techniques, but if we take the systems view of these we might say that these techniques provide solutions for problems which have not been sufficiently defined, and as a consequence these solutions might suggest policies which are not consonant with the higher level goals of the system. This is true for the tunas and in order to arrive at a non-intuitive policy we need to, at least, first define the system in terms of (1) its inputs and outputs, (2) the overall goals of the system, (3) the measures of performance, (4) the system environment (that is the components which are not modifiable by the system), (5) the system resources (the components which are modifiable and utilizable within the system) and (6) lastly the management of the system. We must then think of alternative systems and determine whether these alternatives are better than the existent system.

We can then see that our strategies essentially involve, as pointed out previously, adjusting effort and size at recruitment to some optimal levels which in practice, usually does not involve important problems of mixed-species fisheries; a stock or a collection of stocks fished by several countries, or economic problems. Because of this situation we have no guidance for the situation where, for example, one stock is exploited, depleted to some level, then abandoned for another stock. It is clear that the possibility for strategic management in fisheries (that is the technological tools) far exceeds our software and capabilities for management of these stocks.

In contrast to the wealth of specialized advice that is available for managing fisheries at the strategic level, there is virtually no information on the tactical or operational aspects of fishing. We can for the sake of discussion view one tactical problem as the allocation of a fleet to fishing grounds and an operational problem as perhaps day-to-day guidance on fishing vessel strategies. Again it is difficult to formulate specific solutions for general tactical or operational problems. We will, however, to demonstrate the feasibility of such an approach, apply the theory of dynamic programming.

TABLE 4

Catch, effort, and percent contribution of 1939 year class (by weight) for the Georges Bank haddock stock (after Royce and Schuck 1954)

Year	Total catch millions of lb (rounded)	Days fished (000's)	Percent contribution of 1939 year class by weight
1931	115	12.9	-
1932	105	9.1	-
1933	82	8.4	-
1934	50	4.8	-
1935	79	6.4	-
1936	84	6.2	-
1937	96	8.2	-
1938	92	7.8	-
1939	105	8.0	-
1940	93	7.2	2.3
1941	122	7.3	29.5
1942	107	5.7	33.8
1943	90	4.8	25.7
1944	96	5.6	21.4
1945	78	4.8	13.5
1946	104	7.3	9.2
1947	105	8.2	4.1
1948	94	7.7	2.6
1949	82	7.1	-
1950	81	5.7	-

There are many possible strategies that can be used on a tactical or operational level. For example, we may want to provide guidance on the route of a fishing vessel. Let us construct a simple dynamic programming example of optimizing the route of a fishing vessel. Suppose we have a vessel capable of fishing for 3 days. The fishing grounds and the expected daily catch on each are as follows:

Port	Fishing Ground I	Fishing Ground II	Fishing Ground III	Fishing Ground IV
	Expected catch = 2 units	Expected catch = 4 units	Expected catch = 3 units	Expected catch = 7 units

Let us assume that if we are in any fishing ground on any day and remain in that fishing ground on the next day then we can catch, on the next day, the full expected catch. If, however, we decide to move to another ground we must pay a penalty in lost fishing time. In order to keep the arithmetic simple we reduce the catch by one unit for moves of +1 or −1; 2 units for moves of ± 2, moves $> \pm 2$ reduce the catch to zero. Thus on the first day transitions between port and each of the four areas would yield the following catches:

From \ To	1	2	3	4
Port	2	3	0	0

on the second and third day we would have catches as follows:

From \ To	1	2	3	4
1	2	3	1	0
2	1	4	2	5
3	0	3	3	6
4	0	2	2	7

and on the final day we pay the following penalties which are related to our distance from port at the completion of the fishing trip.

From \ To	Port
1	0
2	−1
3	−2
4	−4

Given these data we can use the dynamic programming algorithm to find the route which will maximize catch. We begin with the last day and work toward the first. The consequences, with respect to the model, of being in any location on the fourth day are in the above table. The catches, adjusted for penalties on the third day, are based on our decision on the fourth day and are as follows:

From \ To	1	2	3	4
1	2 - 0 = 2	3 - 1 = 2	1 - 2 = -1	0 - 4 = -4 *
2	1 - 0 = 1	4 - 1 = 3	2 - 2 = 0	5 - 4 = 1
3	0 - 0 = 0	3 - 1 = 2	3 - 2 = 1	6 - 4 = 2
4	0 - 0 = 0	2 - 1 = 1	2 - 2 = 0	7 - 4 = 3

*(Catch on third day if we transit from 1 to 4) - (penalty for being in 4 on last day) = (cumulative catch for 1 → 4 → port route)

Pursuing the above table shows that cumulative catch that we would expect if we were in a particular location and chose another location for the next day of fishing. We can then determine from the catch maximizing decision for any starting point from the table. These catch-maximizing decisions are as follows:

From	Destination for maximum catch	Maximum catch
1	1 or 2	2
2	2	3
3	3 or 4	2
4	4	3

Now preceding to the next previous stage we add the maximum catches from the above decisions to the transitions for the preceding day obtaining the cumulative catches for the next previous stage, which are:

From \ To	1	2	3	4
1	4	6	3	3
2	3	7	4	8
3	0	7	5	9
4	0	5	4	10

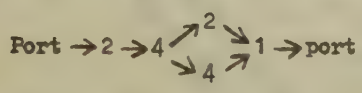
and these yield the following catch maximizing decisions:

From	Destination for maximum catch	Maximum catch
1	2	6
2	4	8
3	4	9
4	4	10

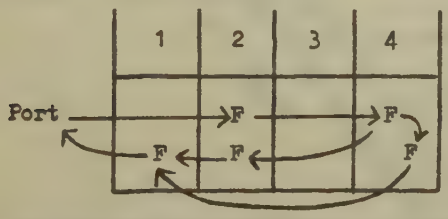
We then apply these to returning to port obtaining the initial optimal decision:

From \ To	1	2	3	4
Port	8	11	9	10

and we can see here that the optimal decision is location 2 and yields an expected cumulative catch of 11 units. So the optimal path(s) which maximize catch less travel penalties is



The vessel track would be



We can see then that there is a rather large opportunity to consider strategic, tactical and operational views of a fishing system. There is an interesting aspect of this opportunity and this reflects from the iterative nature of systems analysis which states that we might wish to reformulate our problem after we have examined it from a systems viewpoint. Our reformulations, in this case, would be to modify what we customarily consider to be a strategic view of fisheries in light of the possibility that in managing fisheries as a total system, we might wish to include, in our concepts, the tactical and operational view as well.

It is apparent that, as we increase the complexity of our concept of management, we will need to formulate an information system so that we can have flexibility in making management (in the broad sense) decisions and formulating policies. As a beginning we can consider applying modifications of the management information concept forwarded by Blumenthal (1969).

We begin by constructing a fishery "environment" in which, following Blumenthal's use of Forrester's terminology, there exists a series of "levels". The levels reflect the present value of stock size, species composition, fleet position, inventory at sea, inventory on shore, etc. Each level is a black box which contains a data capture device which transmits data from the environment (see Figure 7) to the various management systems (Figure 8). We make no distinction at this point between nature's

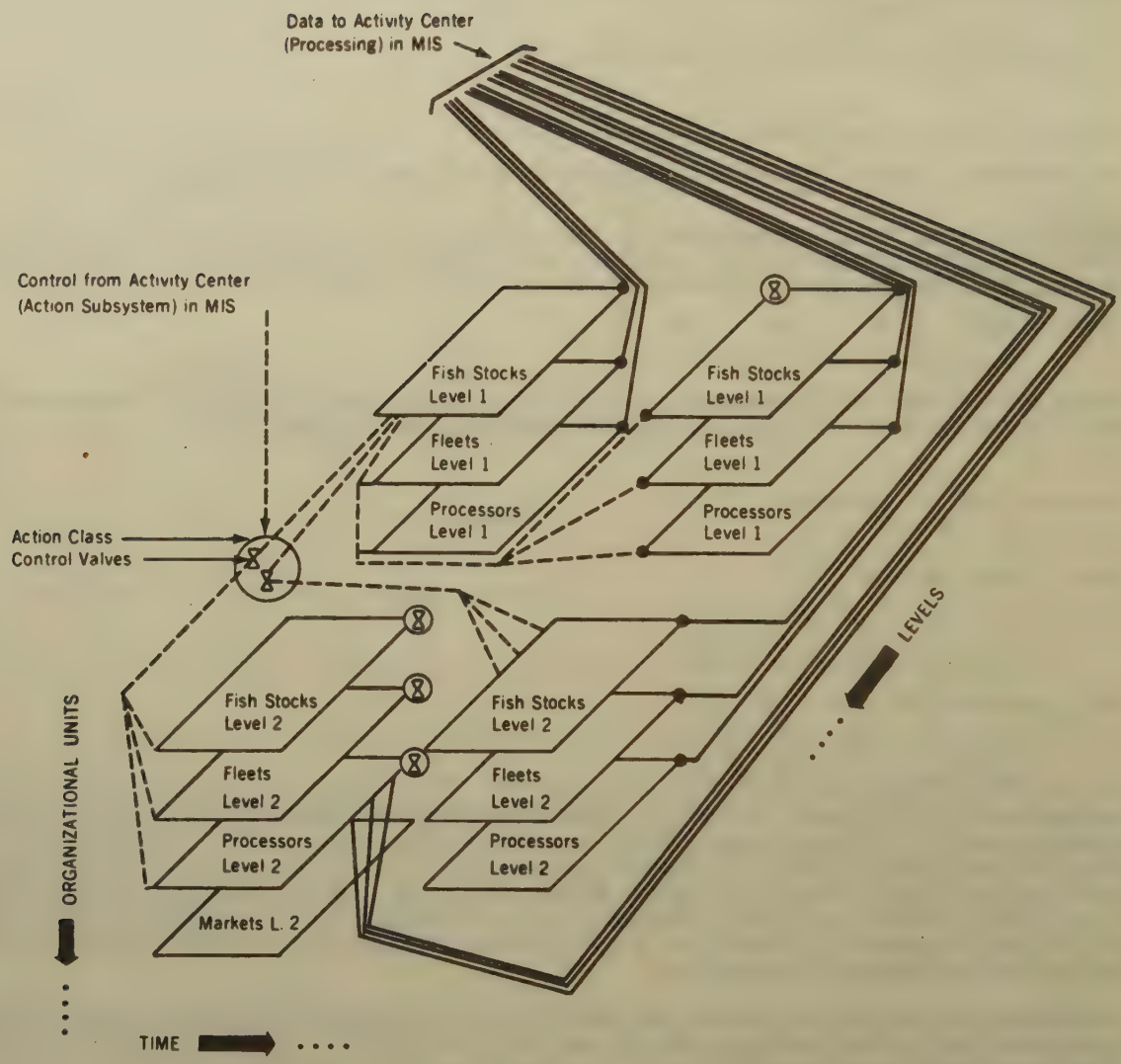


Figure 7. Skeleton of the fishery environment and its interfaces with the management information system.

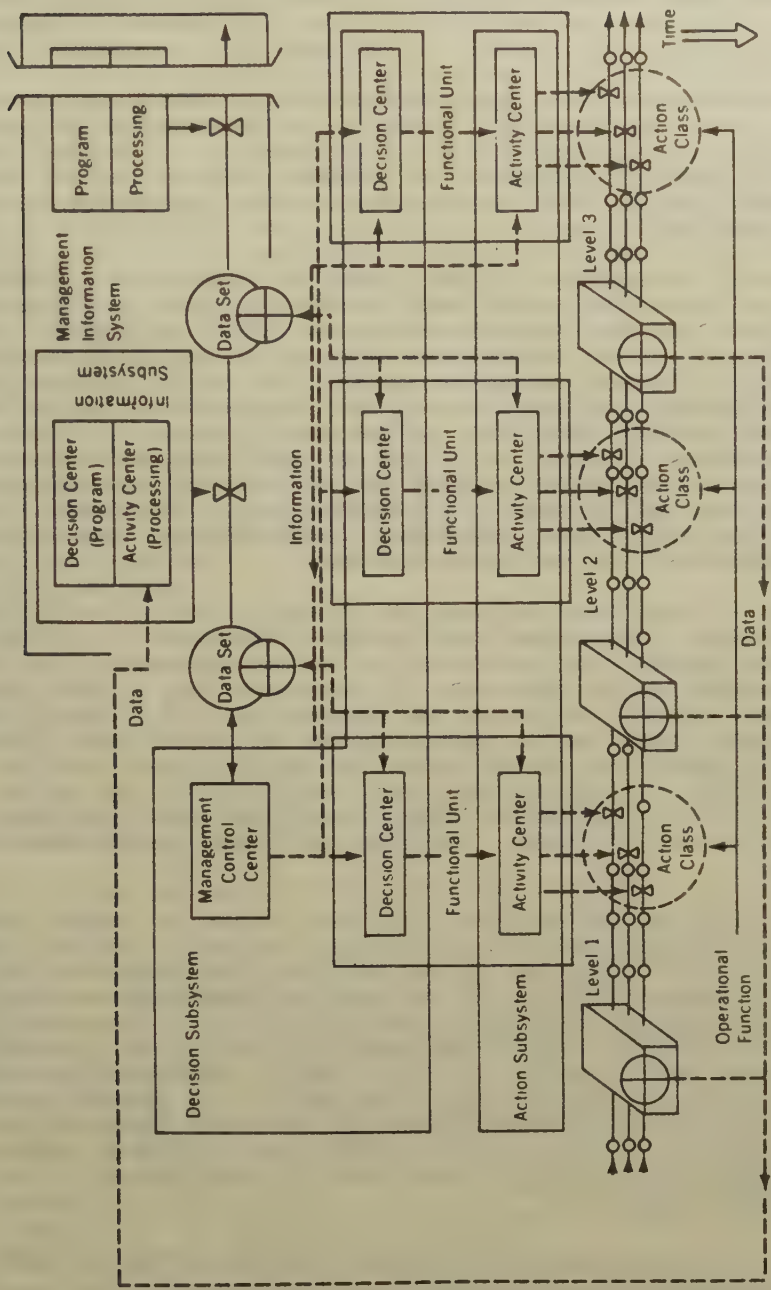


Figure 8 Management information system as outlined by Blumenthal (1969).

management and man's management. In terms of nature's management there is of course, hopefully, a considerably greater degree of ambiguity and equivocation in the actions which are communicated and the data which are transmitted. Generally speaking, pertinent wires in each cable control the rate of flow between the levels and again control is not necessarily deterministic. The rates of flow in each cable are generally controlled by an activity centre which is guided in a functional unit by a decision centre. The decision centres are guided by a management control centre. The collection of activity centres constitute the action sub-system and the collection of decision centres plus the management control centre constitute the decision sub-system. The decision sub-system plus the action sub-system plus the environment essentially form the substrate for the management information system.

The utility of such an information system should be obvious. The applications can relate to the more sophisticated integrated system providing information to the fisherman and the processor or to the extant fishing operation or to segments of the extant operation. It is clear that, for example, there are no virtual real-time data available on the collective tuna fishing operations of the world. If we are to manage these fisheries, most of which involve several species and several fishing nations we will simply need to have timely data.

The important question that we face is the implementation of a systems-oriented approach to fisheries. One view is to take the so-called "total systems approach". A total systems approach to the tuna fishing problems of the world is not something that we can easily define without further detailed analysis and even if we could define a total systems approach for managing tuna fisheries, there would most likely be a time lag, perhaps considerable, before the fisheries could be integrated toward a unified systems concept. On the other hand, if we consider the proper utilization of our resources then we would be severely remiss if we did not acknowledge the complexities of the total system and try to solve them. I hasten to add that this does not mean, because there are, for example, economic problems related to the fisheries that we should emphasize the study of economics by itself. Rather, it does mean that the study of a particular fishery system and all conceivable fishery systems relevant to the particular fishery system should acknowledge the economic problems and incorporate the economic problems in a total view of the problem.

In this connection, it is pertinent to peruse the various reports of the FAO Expert panel for the facilitation of tuna research. This perusal might reflect a high degree of concern by tuna researchers of the world with various techniques and activities such as tuna taxonomy and tuna tagging. These are, in some, but not all contexts, useful techniques. If, however, we were to take a systems view we would instead concentrate upon the problems of tuna management and how to resolve them. We would in particular concentrate upon formulating the various problems in terms of their objectives, context, assumptions, criteria and hypotheses. We would search for necessary data, elucidate relationships, form necessary approximations, look at alternatives and identify costs. The various resulting alternatives would be constructed by the construction of models and these would be adjudged in terms of sensitivity analysis and cost-effectiveness. The system could then be interpreted in terms of contingencies and uncertainties.

Finally, we arrive at the actions that need to be taken to turn the systems view into action and these involve questions of the attitudes of the institutions involved in making decisions on the future of the fisheries. Whether the institutions can take a systems view depends upon the enlightment of administration and the influence extended by the community of individuals associated with the fishing industry (fishermen, scientists, and businessmen) and their ability to communicate these concepts to appropriate funding entities. This communication depends, of course, upon political considerations, but it also depends, rather heavily, upon being able to talk the language of the funding entities which are also taking systems views. In so doing many funding entities are emphasizing programme budgeting. I have already outlined some of the philosophical problems associated with building a basis for programme budgeting (Rothschild and Uchida, 1968). In the administration of problems associated with programme budgeting there are several concepts which should be considered and I have outlined these elsewhere (Rothschild, 1967)

> Consideration of programmes should not be limited to fixed objectives, adjusting inputs and outputs to meet these. Rather, the objective should be considered as a variable and the several values of this variable should be considered among the alternatives.
>
> Budgeting should concentrate on allocation of activities rather than on being utilized as a tool of management.

Budgeting should not focus on functions, the individual's accomplishments to be achieved and the work to be done. These should be regarded as intermediary processes. Budgeting should concentrate on the aggregate of these intermediary processes.

Budgets should evaluate programmes rather than activities.

In budgeting the incremental-decremental approach should be avoided in favour of viewing alternative programmes.

In summary, then, I have attempted to consider the fundamental problems of tuna management. In so doing I have taken a systems approach. This approach suggests that the tuna fisheries of the world have not been described as systems and that, accordingly, there are no guidelines for how these important fisheries should be managed. The existing management concepts are mostly strategic, involving yield per recruit analysis, which we can make more complex than the data which are available to us; general production analysis which could require a rather delicate understanding of the way in which effort is measured, particularly in a fishery that is changing dynamically; and the use of stock and recruitment which is most likely of little use in managing tuna fisheries, at least with existing techniques. While these problems are certainly important, it would appear to me that the aforementioned problems of allocation are at the heart of conserving the tuna resources where, by "conserving", we mean that action whereby man makes the best use of the resource. While there have been various allocation schemes, such as leasing or licensing fishery shares, I do not believe that we have enough timely information about tuna catches, effort distribution, landed fish distribution, added values, etc., to actually understand the tuna "system" on a worldwide basis to adequately formulate the tuna problem as a systems problem and for this reason it would be unwise to propose particular allocation schemes for either the status quo situations or for future likely situations. It would therefore seem advisable to begin to define the tuna "system".

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